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ABSTRACT

With the increasing importance of sharing computer-based information between tactical platforms, the Australian Defence Force (ADF) is aware of the need to enhance its ability to distribute such information, to those who need it, in a timely fashion.

There are many systems available or being developed that can contribute to meeting this requirement. This report describes the capabilities provided by a selection of technologies, considered to be of potential relevance to the ADF. This includes enhancements to Link-16, the Improved Data Modem (IDM), Link-22 and the Common Data Link (CDL).

A discussion of the interoperability issues that need to be considered when implementing any such systems in the ADF, is also included.

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Executive Summary

With the increasing importance of sharing computer-based information between tactical platforms, the Australian Defence Force (ADF) is aware of the need to enhance its ability to distribute such information, to those who need it, in a timely fashion. This is important not only amongst the platforms of the ADF but also when working in combined operations with other nations.

There are many systems available or being developed around the world that can contribute to meeting this requirement. Some serve more more generalised purposes while others fulfil a narrow role. This report describes the capabilities provided by a selection of technologies, considered to be of potential relevance to the ADF.

The first of these is Link-16. It is not yet used by Australia but this system has been in use by other nations for several years. There is also an ongoing effort to enhance its capabilities. Some of these developments, such as the JTIDS/MIDS terminals, time slot reallocation (TSR), Link-16 enhanced throughput (LET) and multi-TADIL processor are discussed in this report.

The Improved Data Modem (IDM) is a device that has been developed as a short-term approach to providing tactical data transfer capability to platforms that have previously relied on voice communications. A general description of its features is provided.

Link-22 is currently being developed and tested in the US, and is aimed at addressing some of the problems and inadequecies of Link-11. Hence it is seen as an eventual replacement for it. Link-22's capabilities, particularly in comparison to Link-11 and Link-16, are detailed.

The term Common Data Link (CDL) refers to a family of tactical data links that support reconnaissance and surveillance operations. An overview of the various links in this family, and their operation, is given.

Finally, to emphasise wide ranging complexity involved when implementing these data link systems, a discussion of the interoperability issues that need to be considered, is also included. This is viewed from the perspective of interoperability within the ADF, and also of the ADF with coalition partners.

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John Asenstorfer obtained his BSc (Hons), BMaSc (Hons) and BE from Adelaide University. After Working at BHP (Whyalla) for 3 years he joined the lecturing staff at the SAIT. He obtained his ME (Research) from the SAIT and then his PhD from the University of Adelaide. He lectured and conducted research in the areas of digital communications and computer systems.

Prior to joining DSTO John lead the Mobile Communications Laboratory, for 5 years, within the Institute for telecommunications Research at the University of South Australia, working in the wireless networks area covering: multi-user spread spectrum, wireless ATM, multi-user access and dynamic bandwidth management.

In early 1999 he joined DSTO, and has worked in communication systems analysis and architecting. Currently John is Head of Network Architectures in Military Communications Branch.

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Contents

Abbreviations

ADF	Australian Defence Force
ADFTA	ADF TDL Authority
ADGE	Air Defence Ground Environment
AEW&C	Air Early Warning and Control
C2	Command and Control
C2P	Command and Control Processor
C3	Command, Control and Communications
CDL	Common Data Link
CHBDL	Common High Bandwidth Data Link
COP	Common Operating Picture
DLPS	Data Link Processor System
EPLRS	Enhanced Position Location Reporting System
FDL	Fighter Data Link
HIDL	High Integrity Data Link
HUG	Hornet UpGrade
IDM	Improved Data Modem
IJMS	Interim JTIDS Messaging System
JRE	Joint Range Extension
JTIDS	Joint Tactical Information Distribution System
LCCDL	Limited Capability Common Data Link
LET	Link Enhanced Throughput
LMT2	Link-16 Missile and Tactical Terminal
LVT	Low Volume Terminal
MIDAS	Multi-link Interoperability Data Analysis System
MIDL	Modular Interoperable Data Link
MIDS	Multifunctional Information Distribution System
MIST	Modular Interoperable Surface Terminal
NATO	North Atlantic Treaty Organisation
NILE	NATO Improved Link Eleven
PCIDM	Personal Computer IDM
SADL	Situation Awareness Data Link
SIAP	Single Integrated Air Picture
STDL	Satellite Tactical Data Link
TADIL	TActical Digital Information Link
TCDL	Tactical Common Data Link
TDL	Tactical Data Link
TDS	Tactical Data System
TIGDL	Tactical Interoperable Ground Data Link
TIM	Transportable Interoperability Monitor
TSR	Timeslot Reallocation
TULIP	ThroUgh Life Interoperability Planning
USA	United States Army
USAF	United States Air Force
USN	United States Navy
VMF	Variable Message Format

1. Introduction

This report provides an overview of the current status of various emerging data link technologies and the directions in which they are heading. The intent is to give the reader a general appreciation of these areas and provide a basis upon which further knowledge can be built through other resources. Note that, in this report, the term TADILs (TActical Digital Information Link) is used to refer to network systems that pass processed tactical data (for example Link-16) while the term Tactical Data Links (TDLs) has wider application, encompassing Tadils as well as tactical data systems that pass raw or unformatted data.

Chapter 2 focusses on Link-16 technology. Although this communication system was originally designed many years ago, it is currently entering a phase of rapid uptake by many platforms in many countries, particularly with the introduction of the Multifunctional Information Distribution System (MIDS) terminal. This is resulting in moves to enhance its capability, while maintaining compatibility with the existing system. These various aspects of Link-16's evolution and development are discussed in Chapter 2. We also briefly describe its integration with other communications technologies through multi-TADIL processors and software defined radios.

The Improved Data Modem (IDM) is a device that is used in conjunction with existing communications equipment and platform mission systems to create a form of data link. This enables a platform to have improved situational awareness in cases where the implementation of a fully featured data link system such as Link-16 may not be necessary or appropriate. The features of this device are covered in Chapter 3.

In Chapter 4, a data link system yet to see operational usage is discussed – Link 22. The original motivation for the development of this system was to overcome some of the deficiencies of Link 11 and to eventually replace it. Its design has evolved so that it can closely interoperate with and complement Link-16.

The role and basic operation of a family of data links known as Common Data Link (CDL), is presented in Chapter 5. CDL is designed to specifically support reconnaissance or surveillance operations.

Chapter 6 is the last major section and investigates some of the interoperability issues encountered when trying to achieve information flow between the various data link systems that Australia will have, and also with the systems of other nations. The report is completed with some concluding remarks in Chapter 7.

The technology and interoperability issues involved with the use Variable Message Format (VMF) will not be explored in this report as this will be the subject of another report to be produced under the Tactical Data Links task running in Information Networks Division.

2. Data Link Evolution and Development

Changes are being made to the waveforms and terminals for Link-11 and Link-16 to improve capability. These are discussed below.

2.1 Link-16 Terminals

2.1.1 Introduction

Link-16 is a complex TADIL designed to meet the needs of military users for reliable, accurate and timely tactical information. Its performance is realised through the implementation of the hardware (the communications component) and software (the information component). The peak data rate can reach 238kbits/second, but the typical rate is usually considerably lower than this value for all but specific-use conditions. The current standard for Link-16 messaging is defined in MIL-STD-6016 (currently at revision B), although significant subsets of that standard are more precisely specified for practical implementation purposes. The messages defined in MIL-STD-6016 are known as the J-series message set. The formatting and error-correcting capability in the Link-16 J-series message has a maximum data rate of 107.52kbits/second, although there are lower rate, more commonly used modes of 26.88 and 53.76kbits/second.

2.1.2 JTIDS Terminals

The Joint Tactical Information Distribution System (JTIDS) hardware implementation of the Link-16 standard commenced in 1969. Technology issues hampered developments and in 1974 the Service JTIDS were directed to combine into a single joint program. The first generation JTIDS terminals were produced as a result of 20 years of development of the Link-16 hardware and software. The early versions of these terminals (JTIDS Class 1) were limited in capability and were not widely distributed in operational units. Initial implementation was for the United States Air Force (USAF) and North Atlantic Treaty Organisation (NATO) E-3 Sentry Airborne Warning and Control System (AWACS) aircraft. They implemented a prototype capability designated the Interim JTIDS Messaging system (IJMS). The second generation terminals (JTIDS Class 2) provided the full capability required to implement Link-16 J-series messages, as against the IJMS. In the 1980s and early 1990s, a series of operational tests were conducted by the US Navy and Airforce to evaluate JTIDS Class 2 terminals. These Class 2 terminals were first produced in the early 1990s for the US Navy (USN), US Army (USA) and USAF. A series of problems were noted: high terminal failure rates, short lifetimes of key components and software reliability problems. Because of the diverse range of requirements, no single configuration could meet all requirements, so several hardware and software configurations have been developed. For example, to meet interoperability requirements until full conversion has been achieved, only the USAF and NATO E-3 JTIDS Class 2 terminals can handle

both the J-series messages and the IJMS messages. This conversion is nearing completion.

Typical configurations of JTIDS Class 2 terminals include:

- The USN JTIDS Class 2 or JTIDS Class 2-H, as used in a shipboard configuration. The "H" configuration refers to a High Power Amplifier (HPA) module added to boost the output power of the 200W JTIDS Class 2 Terminal to 1kW to provide greater range performance and jammer 'burn through'. These terminals require a large mounting rack to accommodate all the modules required.

- Airborne JTIDS Class 2 and JTIDS Class 2-H terminals as used by the USN, USAF and NATO for airborne applications on platforms such as the F-14 Tomcat fighter and E-3 Sentry AWACS. These terminals have cooling systems and power supplies to suit the airborne environment.

- The US Army special ground-based, ruggedised JTIDS Class 2-M terminal which has built-in cooling fans and power conditioner. Instead of being mounted in a rack, it is completely contained within an enclosure box. Some features, such as TACtical Air Navigation (TACAN), are removed from the JTIDS Class 2-M terminal.

All terminals have the same core electronic modules to meet the requirements of the Link-16 performance and implement the J-series messages. The software loads for the various terminals have about 70% commonality. The remainder supports the unique service-specific requirements.

The common problem with the JTIDS Class 2 family of terminals is their effective "technological age". Terminals designed over 10 years ago will inevitably have difficulties in hardware supportability. As components become scarce or unobtainable, modules must be redesigned to provide continuing capability. This is a problem which is being rapidly exacerbated through higher integration displacement of older generation components. Although Class 2 terminals provided to the Australian Defence Force (ADF) through Foreign Military Sales (FMS) channels have a specified 15-year life support contract, the ability of the supplier to meet these requirements, despite contractual obligations, will become strained over the next decade. Beyond that period other factors (discussed below) will also impact on supportability.

The problem facing the older JTIDS Class 2 terminal family is that its design is not conducive to modernisation programs. Worse, no funding or proposals have been made or are known to be seriously considered, to address such issues. The US contention is that the MIDS terminals will replace the JTIDS Class 2 terminals by the time such capabilities are required in the latter half of this decade. An issue not fully addressed in this argument is how interoperability can be maximised during the inevitable period of conversion. The ADF will face this problem because it has already

ordered, or is in the process of ordering, JTIDS Class 2 terminals for the Frigates (FFG), Air Defence Ground Environment (ADGE) and Air Early Warning and Control (AEW&C) projects. Because Australia is not a member of the MIDS Consortium, it must wait until the primary orders for MIDS terminals are satisfied for the member nations. With current delays and increasing order levels, the backlog of terminals to be manufactured for the consortium member nations is increasing. The ADF may be hard-pressed to obtain adequate supplies of production-run MIDS terminals before 2005. Shipboard (e.g. FFG), ground (e.g. ADGE) and to some extent larger airborne platforms (e.g. AEW&C or AP-3C) can use the Class 2 terminal. However, severe space, power and environmental control system (ECS) limitations dictate that the MIDS terminals are absolutely critical for the AIR5376 F/A-18 Hornet UpGrade (HUG) program.

2.1.3 The MIDS Program

The Gulf War raised the importance of data communications and situation awareness, and the rapid transfer of targeting and threat information. The mid nineties also saw a series of successful trials using JTIDS, which fuelled the development of further JTIDS terminals in particular the Class 2R for the F-15.

At approximately the same time US and NATO started developing the MIDS terminal. The Multi-function Information Distribution (MIDS) Low Volume Terminal is a US led international program which implements Link-16 compatible data communications terminals. The JTIDS waveform and TADIL J message catalogue are supported. The countries funding the development are, in order of contribution: US, France, Germany, Italy and Spain. The MIDS International Program Office (IPO) is based at US Navy's Space and Naval Warfare Systems Center (SPAWAR).

MIDS will provide interoperable data communications that will link fighter aircraft to air controllers, intelligence, surveillance and reconnaissance (ISR) collection assets, air and ground based command and control (C2) nodes. Currently world wide, fighter aircraft have very limited data communications and restricted voice communications between selected nodes. During the development the USAF became increasingly concerned with the cost and reliability of the Class 2R. In 1993 the MIDS program was restructured, in a way that emphasised open architecture and the use of commercial off-the-shelf (COTS) parts. In 1995 the class 2R terminal project was terminated in favour of the MIDS Low Volume Terminal (LVT) terminal. Since the USAF had an urgent need for a Link-16 capability in it's F-15s, a solution was pursued that was based on MIDS and named Fighter Data Link (FDL). This approach bypassed the normal MIDS agreements on MIDS program decisions, production and supply, in order to obtain an operational capability as soon as possible.

In 1995 the US Army contracted an LVT and the US Airforce's LVT contract was awarded third quarter 1996. The MIDS terminal program was delayed in 1999 due to the lack of terminals available to member countries which delayed terminal-platform integration activities. Only 19 terminals were available of the 33 terminals originally

programmed. The late entry of the USAF FDL contract has put extra pressure on the engineering manufacturing and development (EMD) IPO. The exit cost of the MIDS terminal must meet a cost criterion of $250,000. The shortage of terminals was due to the slow delivery of some of the terminal cards. The delay has caused a slip in fielding the first Link-16 capable F-16 squadron to the third quarter of CY03.

The FDL terminals for the F-15 squadron were due for delivery in 1998 but due to engineering change proposals it was initially expected to be 22 months later than the original Class 2R terminal.

As Australia has not contributed to the development of MIDS it will have to wait to get access to production terminals. Any early access to production terminals can only occur through intervention on our behalf by the US. The international program is in part a strategy to obtain interoperability between US and NATO, including combined logistics. Despite an international program being more expensive than a domestic program, the payback should come with the high levels of interoperability between the US and NATO.

Some of the goals that the MIDS program was to address include:
1. Operational interoperability of C2 and surveillance capabilities
2. Interoperability of ground, air and maritime C2 centres
3. The use of a participant position location and identification function that can provide Identification Friend or Foe (IFF) functions
4. The provision of precise position and status information of all aircraft in a coalition force that bridges language barriers and helps integrate the force
5. Facilitation of technology exchange between the US and NATO countries (almost all other attempts failed)
6. Allowing Europe to purchase local military product
7. For the US, increased levels of interoperability.

The hardware development responsibilities for the LVT development phase have been as follows:
1) The chassis, interim power supply and battery are manufactured by GEC-Marconi (US contractor)
2) The MIDS LVT TACAN, signal processing, message processing and real-time interface are manufactured by GEC-Marconi
3) The power amplifier is manufactured by Siemens (Germany)
4) The receiver-synthesiser cards are manufactured by Thompson-CSF (France)
5) The voice card, tactical processor and data processor by ENOSA (Italy)
6) The exciter/intermediate pulse frequency are manufactured by a European consortium

The contractor team for the production terminals may differ considerably from the LVT EMD terminal contractor team. The terminal's architecture is based on the open VME

bus standard and all cards, controllers and processors communicate with each other through the VME back-plane.

The USAF FDL terminal is 80% hardware and software compatible with the MIDS LVT. Some cards had to be different from the MIDS terminal because of the F-15 avionics. The combining of the programs should be considered as positive as it should ensure its continuation and higher levels of interoperability for Link-16

The MIDS terminal is based on an open architecture with the purpose of assisting integration into a variety of platforms.

The MIDS LVT primary interface into the air platform is through the avionics bus (e.g. the 1553 bus). Through the bus it has access to the cockpit I/O devices such as numeric keypads, cockpit displays showing air threats or targets, communications and navigation antennae, and on-board processors. The MIDS rack houses 9 standard modules with card level interoperability. The MIDS software architecture comprises two parts. The first supports basic functions such as message processing, signal processing and Link-16 waveform generation. The second part supports all of the I/O functions, currently at around 340,000 lines of code.

Power levels for operation were agreed to be 200 watts for the Link-16 and TACAN transmitters. France wanted the radio to operate at each of 1, 40 and 200 watts and to have a receive-only mode. The original JTIDS terminals, in order to support robustness in a jamming environment, had 8 receiver-synthesisers but due to the size and power limitations, MIDS uses a 4 receiver-synthesiser design. As the MIDS terminal will be used in a range of operations it requires a significant capability for software programmability to support the range of scenarios and missions that it will have to operate in.

The platforms that will be fitted with MIDS terminals in the US and Europe include:
1. Rafale, EF2000, EF-18, AMX, F/A-18, F-16
2. ACSS platforms
3. Navy and Army platforms, Army ground C2, Frigates
4. Airforce ground C2

Because of the later design period, supportability of the MIDS terminal family is less of an issue than the Class 2 terminal. Concepts for improving the performance and providing work-around solutions for limitations on the use of Link-16 are already being processed for the MIDS terminals:
- The inclusion of Link Enhanced Throughput (LET) will increase the link data rate by between 3 and 10 times its current capacity, albeit with trade-offs in other performance parameters such as range and anti-jam capacity.
- Because Link-16 uses the Aeronautical Radio Navigation Services (ARNS) band (960-1215MHz) as a secondary user, it must be subservient to any encroachment on its spectrum by the primary users. Global Positioning Service (GPS)

expansion through the implementation of its L5 integrity signal at 1176.450MHz, and the European Galileo Air Traffic Control (ATC) satellite service in the top 50MHz of the ARNS band may force Link-16 terminals of all format to be either modified for reduced frequency allocation, to be limited to single frequency operation (969MHz) or be discarded if appropriate modifications can not be installed. A component of this modification may also include expansion of the Interference Protection Feature (IPF) hardware and/or software.

These improvements should be available by the time full rate production commences in about 2002. Card-level changeovers will cater for those terminals already existing through the Low Rate Initial Production (LRIP) process.

2.1.4 Interoperability

The development effort for MIDS has been distributed according to the MIDS-EMD Program, and involves the following cost shares: US-41%, France-26.5%, Italy-18%, Germany-7.5%, and Spain-7% (59% borne by European partners).

The original class 2R terminals that were cancelled were to be built to the cost criteria of $160000. The Rockwell-Collins Sea Harrier (SHAR) terminal is a derivative of the 2R terminal and its cost, at approximately half way between the 2R terminal target cost and that of the MIDS terminal, may be representative of what the 2R terminals may have cost. The FDL program, however, using common components with the MIDS terminal will ensure a much greater level of interoperability with MIDS (primarily US Navy funded). The situation of the SHAR terminal is complicated by the fact that Rockwell-Collins is a partner in Data Link Systems (DLS), the prime contractor for the FDL program. SHAR (now renamed UK LVT) probably benefited substantially from the Research, Development, Test and Evaluation (RDT&E) investments for the MIDS terminal. The US would have saved money by pursuing a JTIDS terminal procurement, but NATO partners would not have accepted procurement of a purely US system. The extra investment is in effect in interoperability with NATO partners.

2.1.5 Summary and Conclusions

The major issues associated with the LVT are:
1) Increasing software complexity
2) One year delay in availability of low rate initial production terminals
3) MIDS IPO production plan
4) Platform integration skills

The LVT and FDL terminals are now inextricably linked and will ensure the continued viability of the MIDS terminal.

2.2 Timeslot Reallocation (TSR)

Timeslot reallocation (TSR) is a Link-16 transmission timeslot access method. It is based on an algorithm that automatically shares terminal access to a common pool of Time Division Multiplexed (TDM) slots based on their expected demand. This is in contrast to other access methods in which the transmit opportunities (timeslots) are fixed and cannot be changed automatically to suit varying transmit requirements. With these other access methods, timeslot allocations can only be changed by the intervention of the network manager. This is not a highly responsive approach and a network manager may not always be available. So TSR will bring the benefits of greater responsiveness to transmission demands, flexibility to accommodate unanticipated participants and easier network management.

TSR involves a pool of timeslots being collectively allocated to a group of terminals. For each terminal to participate in the allocation of timeslots, it must possess the common TSR algorithm in software. As the algorithm is distributed, there is no single point of failure. The allocation is executed over TSR periods. Each terminal announces its capacity requirements for the next period towards the end of the current period. This information is disseminated among terminals (causing some extra loading on the network) so that each terminal is able to assess the total demand on the pool. The TSR algorithm present on each terminal then calculates the timeslots from the pool that each terminal will use in the next period. There may be some overlap in timeslot usage (which can result in contention for the use of those slots) because terminals have an incomplete knowledge of the demands, but this is acceptable in most circumstances.

As there is the possibility of contention and hence increased pulse density, TSR may not be allowed in peacetime operations. Instead a peacetime mode can be used where a master terminal imposes the timeslot allocation. This guarantees unique allocations.

TSR is a recently introduced protocol and is not yet available in currently fielded Link-16 terminals. Some detailed aspects of its design are still being determined and tested. It will be implemented in future MIDS terminals and may also be installed into JTIDS Class 2H terminals. An Interface Change Proposal for TSR was presented to the Joint International Configuration Review Board in September 2000. Consequently TSR should be implemented soon as it only requires software modification.

2.3 Link-16 Enhanced Throughput (LET)

Link-16 Enhanced Throughput is a concept that was developed by Viasat under a contract from the US Air Force. The US Department of Defence (DoD) has selected it as the enhanced throughput standard for Link-16.

The aim of LET was to develop an approach to obtain enhanced throughput over a Link-16 network without significantly increasing implementation complexity or cost, and to do so within the existing Link-16 waveform. The motivation behind obtaining

enhanced throughput (or greater network capacity) was to accommodate increasing network utilisation as more Link-16 terminals are deployed, to enable Link-16 to support higher data rate applications (such as video/imagery and Transport Control Protocol/Internet Protocol (TCP/IP) packet switching) and to make better use of Link-16 networks for existing high data rate applications (such as secure voice).

The tables below compare the throughput of normal Link-16 message types with that of LET messages types. It can be seen that throughput of up to ten times that of Link-16 is possible with LET. The maximum throughput bit rates shown in Table 1 include parity bits.

Table 1: Current JTIDS/MIDS data rate options (Source: Viasat)

Message Types	Maximum Throughput	TADIL J Words/Slot	Relative to P4SP
Standard	28.8 Kbps	3	¼ x
Packed 2 Single Pulse	57.6 Kbps	6	½ x
Packed 2 Double Pulse	57.6 Kbps	6	½ x
Packed 4 Single Pulse	115.2 Kbps	12	1 x

Table 2: LET data rate options (Source: Viasat)

LET Message Type	TADIL J Words/Slot	Relative to P4SP
0	40	3.33 x
1	61	5.08 x
2	93	7.75 x
3	108	9.00 x
4	123	10.25 x

Implementation of LET only involves changes to the Link-16 baseband coding. The combined Reed-Solomon and Cyclic Code Shift Keying (CCSK) coding is replaced with Reed-Solomon/Convolutional coding. This adaptable coding provides a range of data rates, corresponding to the different LET message types (that are identified in the message header). As the coding rate is increased, the data rate increases and the jammer immunity decreases.

A single bit is changed in the synchronisation preamble so that an LET timeslot can be identified. This makes LET terminals backwards compatible with non-LET terminals, as non-LET terminals simply ignore LET timeslots as errored because of the altered

preamble sequence. LET terminals can receive either LET or Link-16 within any timeslot.

LET, otherwise, does not alter the Link-16 waveform. This was done so as not to alter the spectral content and so avoid National Telecommunications and Information Administration (NTIA) certification issues. It uses the same time refinement pulses, encryption, frequency selection algorithm, timeslot burst length, and transmitted pulse structure as current Link-16 terminals.

Note that the increased data rates of LET affect the achievable range of transmission. For example at 1 Mbps, a range of 185 km is possible. Also, there are implementation issues when using these increased data rates. The problem is that the US government specified hardware and software that must be used in the core of the Link-16 terminals cannot cope with the higher data throughput made possible by LET. The 1553 bus also has transfer rate limitations that adversely affect the maximum achievable performance.

The performance of LET prototypes has been evaluated and it has been shown that LET exceeds the performance goals set. So, for the relatively large increase in data rate that LET provides, there is a relatively small degradation in anti-jam performance.

Viasat has incorporated LET capability into current MIDS LVT 2 terminals (the Army variant of the LVT). In addition, LET will be implemented in future MIDS LVT terminals and retrofitted into JTIDS class 2 terminals. The UK is also working on Link-16 Enhanced Throughput, in collaboration with the US, and is considering implementing it in the Eurofighter 2000.

2.4 Multi TADIL Processors

Although there are moves (particularly in the US DoD) to improve interoperability by reducing the number of data link systems in operation, legacy systems will remain in use for some time. In addition, there will always be a need for a number of different data link systems due to differing requirements. As a result, at least some tactical information systems will need to be capable of operating over more than one data link. Multi TADIL Processors (MTPs) are being developed to satisfy this requirement.

The MTP will build on the capabilities of the current Command and Control Processor (C2P). The C2P is capable of concurrent operations on and data forwarding between Link-16, Link-11 and Link-4A. It provides an interface between the combat systems and data link terminals by translating messages and distributing messages. In addition to these capabilities, the future (US Navy) MTP will incorporate S-TADIL-J, Link-22, Joint Range Extension, and other Link-16 enhancements (such as timeslot reallocation). This is planned to be operational by 2004.

The UK equivalent to the C2P, the Data Link Processor System (DLPS), supports message-processing requirements for Link-16, Link-11, Link-14 and Satellite Tactical Data Link (STDL). It also supports data forwarding between those data links, with the exception of Link 14. The future DLPS will support Link-22.

Multi-link operations increase the number of interconnected units, so that (theoretically) all units in a particular tactical operation have a unified and unambiguous view of the situation. However, as a result of this care must be taken in planning and management for multi-link operations, since areas such as track number management, cross link correlation, picture registration, gridlocking and the resolution of differences are increased in complexity.

The level of interoperability achieved depends on which platforms have translation gateways (MTPs) and whether or not these platforms have combat systems that are compliant with Link-16 data message elements.

2.5 Software Defined Radios

Software defined radios (SDRs) that are currently being developed have the potential to improve interoperability and costs for tactical data links. SDRs are radios that can be controlled and configured (to varying degrees) via software.

These radios typically have more than one channel that can each be configured to produce any programmed waveform. Hence one piece of equipment should be capable of operating all data links. New waveforms simply need to be programmed in software and loaded onto the radio. This is how SDRs can improve interoperability. However, the implementation of complex waveforms (such as Link-16) on SDRs is yet to be fully evaluated.

Because SDRs remove the necessity for such a proliferation of different communications equipment on a platform, there is the possibility that they will bring cost savings. The lifetime of the hardware of SDRs should also be longer, as enhancements/updates can be done in software.

Two examples of SDRs are the Motorola Wireless Information Transfer System (WITS) Radio and Rohde & Schwarz's Tactical Software Radio for High Frequency (HF), Very High Frequency (VHF) and Ultra High Frequency (UHF).

Motorola has developed the four channel WITS radio under USN sponsorship. The radio has passed a second major hardware revision and is approaching an off-the-shelf production version. It has been designed to be compliant with the Joint Tactical Radio System (JTRS) open systems architecture. Software is continually being developed and updated (with new features being added and bugs fixed). The WITS radio is currently being integrated into a US Navy platform (the aircraft carrier named the Ronald Reagan), for operational use. It will be capable of interoperability with systems such as

Demand Assigned Multiple Access (DAMA), HaveQuick, SINgle Channel Ground and Air Radio System (SINCGARS), Link-4A and Link-11.

The Rohde & Schwarz's Tactical Software Radio is based on a similar concept to the Motorola WITS radio, although it has some different features, is not based on the JTRS architecture and generally has less capability.

3. Improved Data Modem (IDM)

The Improved Data Modem is a joint service, flight-proven, off-the-shelf system developed by Innovative Concepts Inc for situational awareness. It is a stand-alone modem component which when integrated with on-board radios and host platform computer/processor/display systems, provides data communication. It has the capability to distribute near real-time targeting, position, and tactical data between airborne and ground platforms.

It originated in 1991 when the US Naval Research Lab (NRL) constructed a prototype unit to demonstrate a data link capable of being used across a variety of platforms so that they could participate in a network centric environment. It was adapted from the US Army's Automatic Target Hand-off System I (ATHS I) and the US Airforce's enhancement, ATHS II.

The IDM supports missions such as the suppression of enemy air defences, close air support, airborne forward air control, air combat, joint air attack team, fire support, and command and control.

Data transfer for these missions is made possible by using standard protocols and message sets. Communications protocols currently supported by the IDM include the Air Force Application Program Development (AFAPD), Standard Army Tactical Fire (TACFIRE), Marine Tactical Systems (MTS), Intra-flight Data Link (IDL) and MIL-STD-188-220. The message formats supported are AFAPD, TACFIRE, MTS and Variable Message Format (VMF).

While AFAPD, TACFIRE, MTS and IDL are legacy, waveform-dependent data links, VMF is specified to run over a standardised defence digital message transfer devices (DMTDs). The document that defines the data communications protocols that support DMTD interoperability is MIL-STD-188-220. This standard defines the procedures, protocols and parameters for the interface between the data terminal equipment and the data circuit-terminating equipment. As a result it is not dependent on a particular waveform. MIL-STD-188-220 relates to the physical layer, data link layer and the intranet layer (within the network layer), and covers connection-oriented and connectionless modes of operation.

The content and arrangement of actual VMF messages is defined in the Technical Interface Design Plan - Test Edition (TIDP-TE). This document is in the process of being converted into a US military standard. VMF uses the application header standard defined in MIL-STD-2045-47001.

The IDM is different to a Link-16 terminal in that it is a more generic component and does not incorporate radios. Its flexibility is seen in its capability to interface to many different sets of receiver/transmitter equipment. In addition, by making use of existing radios it is significantly cheaper than a complete terminal. Changing its software allows functionality changes. This makes it adaptable to current and future needs. Room for hardware expansion is also included.

The IDM is an interface between the on-aircraft MIL-STD-1553 A or B data bus and tactical radios (via a cryptographic device). Radios that the IDM can be interfaced with include ARC-164, ARC-182, ARC-186, ARC-201, ARC-210, ARC-222, ARC-225 and PSC-5. There are four half duplex radio channels that can transmit at data rates of 75 to 16,000 bps. Reception or transmission is possible on any of the four channels simultaneously. Each channel can be configured as non-secure analogue, non-secure digital or secure digital (via a KY-58 communications security (COMSEC) device, which is integrated with the IDM family).

The 1553 bus is used to pass messages from the avionics systems to the IDM for transmission over the air and is used by the IDM to forward received messages to the other aircraft systems. It is also used to pass initial setup parameters to the IDM and to monitor its operation.

The hardware that constitutes the IDM consists of numerous Shop-Replaceable Units (SRUs). The two Digital Signal Processor (DSPs) modules provide physical interfacing as well as modulation and demodulation services. The Generic Interface Processor (GIP) carries out link and protocol routing and processing. There is also a power converter, and the chassis assembly.

The software module responsible for the 1553 bus interface is the User Interface/Link Protocol Computer Software Configuration Item (CSCI). This module performs link-level and protocol-level routing and processing for the IDM, including functions such as formatting, parsing headers, encoding, decoding, and storing messages and message receipt and acknowledgement for the four independent link interfaces. It also provides user interface functions, IDM configuration and status information, standard memory load verification, message translation from the 1553 bus, and built-in testing.

The other main software module is the Modem CSCI. This module performs the modulation/demodulation and the physical-level radio interface functions in the IDM. It communicates with the User Interface/Link Protocol CSCI.

A significant amount of network planning and network design is required prior to

deployment. This includes loading the necessary software into the IDM to support the required protocols. The communications protocol used will, of course, affect the behaviour of the network.

IDM units are currently available and are being procured by all US armed forces. The US Army uses the IDM to transmit Joint Surveillance Target Attack Radar System (J-STARS) data from the E-8C aircraft to army command centres, the Ground Station Module (GSM) and attack helicopters. The IDM is also used to pass Longbow radar target data from Longbow-equipped AH-64Ds to other AH-64C/D, OH-58D, AViation Tactical Operation Centres (AVTOCs) or command centres. The US Army is using IDMs on board the Apache Longbow, the Kiowa and the Black Hawk Evac to achieve VMF capability. More IDM units are planned to be acquired for these platforms. The US Air Force has placed the IDM on board 40 F-16C (planned for 247) to allow ground observers assigned to the tactical air control party, using a Mark 7 laser rangefinder, a hand-held GPS receiver and an AN/PRC-113 or 117 UHF/VHF AM/FM radio, to transmit GPS-derived latitude, longitude and elevation of a target on the ground to close air support aircraft patrolling the area. Other platforms where the IDM is in operational service or has completed integration demonstrations include US WAH-64D, EA-6B, O/A-10, A2C2S, UH-60Q, E-2C and several Uninhabited Aerial Vehicle (UAV) platforms, as well as the UK Jaguar.

Companies involved in the production of IDMs include Symetrics Industries (Florida, US), Arinc Inc (Maryland, US) and Innovative Concepts Inc (Virginia, US). A typical unit has a service life of 20 years, weighs 6.3 kg and has dimensions 229 x 188 x 136 mm.

Recent IDM developments include the second generation (2G) IDM, the Personal Computer IDM (PCIDM) and the Video Imagery Module (VIM). The 2G IDM, launched in 1999, includes the addition of increased computing power and mass storage capability to the IDM. Software was changed to allow full compatibility with the Army Tactical Internet. Unlike the first generation IDM that was only capable of point-to-point communications, the 2G IDM implements a fully networked data link system using a TCP/IP-based packet switched system. In this respect the 2G IDM can be characterized as a modem, a router, a gateway, or all three. Other additions include an Enhanced Position Location Reporting System (EPLRS) port, two SINCGARS SIP ports, an Ethernet port and a Universal Serial Bus (USB) port. The Ethernet port can be used as an alternative to the 1553 bus. The 2G IDM also provides six channels, rather than just four, which can each be configured to support different protocols.

The PCIDM is an IDM compatible unit that allows end users to incorporate IDM communications functions into their personal computers via installation of a standard Type II Personal Computer Memory Card International Association (PCMCIA) card. The unit has only two channels, rather than four, and runs under Windows. It incorporates IDM communications functions but has no MIL-STD-1553 bus interface. It has an asynchronous channel and a synchronous channel. The asynchronous channel

can either be operated in a 16kb/s digital mode or a 1.2kb/s analogue mode. The synchronous channel supports MIL-STD-188-144 operation that is typically used in conjunction with cryptographic equipment. Version 2 of this card began shipment in September 2000.

The VIM is a module integrated into the IDM that began development under a USAF project in mid-1997. The primary goal of the project was to equip the Air Force with an imagery system for the F-16C Block 40 that would improve pilot situational awareness when attacking ground targets. To the IDM it adds the ability to capture, compress/decompress and receive/transmit (using the 16 kbps rate) imagery data. It allows imagery capture rates of four images per second and image transmission times of less than 15 seconds. The Defence Evaluation and Research Agency (DERA, now Qinetic) in the UK and the USAF have completed successful demonstrations of IDM terminals with the VIM.

4. Link-22

4.1 Overview

Link-22, TADIL-F and NATO Improved Link Eleven (NILE) are synonymous terms describing an electronic counter measures (ECM) resistant, flexible, beyond line of sight tactical data communications system for linking tactical data systems equipped ships, submarines, aircraft and land-based sites. This data link system supports tactical picture compilation, weapons engagement and status management, and command and control for maritime, airborne early warning and land-based operations.

Link-22 is essentially an improvement that will eventually replace Link-11. It is a multi-network link, capable of operating in both fixed frequency (FF) and frequency hopping (FH) modes in the HF and UHF bands. The data link is currently being developed. Information in this section is based on the proceedings of the Link-22 Symposium in Netherlands, in October 2000.

4.2 The NILE Program

Link-22 is being designed and developed under the NILE Program. Seven countries are participating in this program, including Canada, France, Germany, Italy, Holland, UK and US. The goals of this program have been to develop a data link system that will:

- Meet the needs of the NATO Staff Requirement, 9 Mar 1990.
- Increase the timeliness of tactical data transfer and transmission of high priority warning and force orders, even in a dense and hostile communications threat environment.
- Eventually replace Link-11.

- Complement Link-16.
- Improve Allied interoperability.
- Enhance commanders' war-fighting capability.

The program began in 1989 with a definition phase and then it moved onto the design and development Phase 1 in which Link-22 system and sub-system specifications were developed. These are contained in the standards documents titled STANAG 5522, STANAG 5616, ADatP-22, and Link-22 System Specification. The requirements for the NILE Reference System (NRS) were also developed in this phase. The NRS is a Link-22 compatibility test system. With the completion of Phase 1 the second design and development phase was initiated with Logicon (California, USA) being awarded a contract to develop a System Network Controller (SNC) and the NRS. This was completed in January 2001. At present Logicon is developing a Multi-Link Test Tool (MLTT), which is an interoperability testing system. This is due to be completed in March 2002. In addition, DRS (Philadelphia, PA) is designing and developing a Signal Processing Controller (SPC). The final phase that the NILE program will involve is in-service support.

The program is focused on system design and architecture. Integration, production and implementation of Link-22, based on the work of the NILE program, are the responsibility of individual nations. Currently each of the seven nations is working on this and is at different levels of completion. Predicted final implementation dates range from 2002 to 2009. The US Navy intends to have operational Link-22 systems by 2004, so Link-22 terminals will not be available to the ADF before that time.
The US Navy is the only US service that currently intends to adopt Link-22. However initially Link-22 will be used on less than 5% of US platforms. The Navy plans to install Link-22 on surface C2 platforms to satisfy the beyond line of sight requirements for tactical data exchange not possible using current TADIL J technology. Forwarding capability between Link-16 and Link-22 will be included and Link-22 functionality will be incorporated into the Command and Control Processor (C2P). Other US services may adopt Link-22 in the future as Link-11B becomes obsolete. The Royal Navy and the German Navy are making allowances in current tactical data link systems for future expansion to Link-22 by developing multi-link processors. The Italian Navy intends to finish implementation of Link-22 by 2004 and then install the system on board new aircraft carriers, the Garibaldi aircraft carrier, Horizon Frigates, Multi-purpose Frigates and Destroyers (DDGs).

4.3 Improvements Over Link-11

The current Link-11 system has some significant operational limitations in the modern threat environment. These are related to the fact that it was designed with 1950s technology and that modern day demands on it are greater. There are many more net participants and many more tracks today, greater accuracy is required for modern targeting, there are increased communications threats, and warning and reaction times have decreased. The improvements Link-22 offers over Link-11 are discussed below, in

terms of Link-11 deficiencies.

- **Link 11 has a lack of electronic protection measures.**

The improvements of Link-22 include the use of modern encryption techniques, optional support for radio power control for lower probability of intercept, optional support for frequency hopping radios and the optional use of an adaptive antenna array. Adaptive antenna arrays can provide additional interference and jamming suppression.

- **Link 11 has insufficient tactical message capacity.**

Link-22 provides a significant increase over the 1.800 kbps user data rate of Link-11. Using the HF fixed frequency mode, user data rates of up to 4.053 kbps are possible and with UHF fixed frequency, a user data rate of 12.667 kbps is possible. One Link-22 unit can support up to four networks. A typical configuration would be 3 HF fixed frequency and 1 UHF fixed frequency networks, giving a total rate of up to 24.826 kbps. Alternatively 2 HF fixed frequency and 2 UHF fixed frequency networks could be used, giving a total rate of 33.440 kbps. In addition Link-22 facilitates simultaneous exchange of data for anti-air warfare (AAW), anti-submarine warfare (ASUW), anti-surface warfare (ASW), electronic warfare (EW), theatre ballistic missile defence (TBMD), etc whereas Link-11 typically concentrates on one of these among a small number of platforms.

- **Link-11 is not able to support a large numbers of participating units.**

Although this may not always be a problem, particularly for a smaller defence force like Australia's, it will be significant in joint international missions. Link-22 can support more units per operating frequency than Link-11, when operating at higher data rates. In addition, Link-22 can support up to four different networks per unit and up to eight networks in an extended area of responsibility supporting up to 125 units.

- **Link-11 has insufficient robustness.**

The use of time division multiple access (TDMA) with Link-22 eliminates the Link-11 reliance on two-way connectivity between each unit and the Net Control Station. This improves reliability and total coverage area. Link-22 is able to use message acknowledgements and operate in an enhanced reliability (multiple repeat) mode of message delivery. However, these operating modes are at the expense of data rate. In addition, Link-22 provides redundancy to a unit via time diversity, frequency diversity and antenna pattern diversity. This is because a Link-22 terminal can receive on different frequencies and networks, and may receive relayed messages as well as direct reception. As Link-22 can operate on multiple frequencies, the optimum frequency can be chosen for the prevailing conditions.

- **Link-11 has insufficient error detection and correction.**

Link-22 uses modern error detection and correction with a CRC-16 parity check for residual error detection. Either Reed-Solomon or convolutional coding is used

depending on the waveform.

- **Link-11 has inflexible and slow data link procedures.**

Link-22 has much more flexible and automated network management procedures. It supports dynamic TDMA timeslot reallocation and automated optimization of this allocation. Other capabilities such as rapid link access, priority interrupt, automated late net entry and a variety of message addressing options are also supported.

- **Link-11 message standards have limitations.**

Link-22 has an improved message standard that adds support for land and friendly position/location/identification tracks, has improved granularity for many data elements, and has common positional and hostility index reporting. The message standard employs the same data elements and geodetic coordinate system as Link-16, so data forwarding is easier. This avoids many of the translation and interoperability problems inherent in the Link-11 message standard. Link-22's worldwide geodetic system replaces Link-11's limited delta-range reporting scheme. Link-22 also eliminates the Participating Unit (PU) number, track number and track number block assignment limitations of Link-11. These and other features of Link-11 and Link-22 are compared in Table 3.

Table 3: A comparison of Link-11 and Link-22/Link-16 message features

	Link-11	*Link-22/Link-16*
Address Range	001 - 176	00001 - 77777
Track Numbers	0200 - 7777	00200 - ZZ777
Track Quality	0 - 7	0 - 15
Track Identification	Identity Pri Amp ID Amp	Identity Platform Specific Type Activity Nationality
Status Information	Limited	Detailed
Position Granularity	457 m	10 m
Air Speed Granularity	51 km/h	4 km/h
Lines and Areas	No	Yes
Playing Field	950 x 950 km	Worldwide
EW	Limited	Detailed

In addition to the above aspects, Link-22 also has the advantage that it will make use of existing Link-11 modems, radios and ancillary equipment for fixed frequency operation, and will make use of commercial off the shelf (COTS) computers.

4.4 How Link-22 Complements Link-16

Although Link-22 and Link-16 are both part of the J-series family of tactical data links, they have different features, which make them complementary. Link-16 is primarily an AAW data link and frequently relies on airborne relays to achieve the required range. Link-22 on the other hand is primarily a maritime (ASW/ASUW) data link. It is less reliant on airborne relays as its HF capability has a longer range and ship-to-ship relaying also extends connectivity. Link-22 could also free up additional capacity for Link-16, particularly during high intensity conflicts.

In line with its application, Link-16 is generally capable of higher data rates than Link-22. Link-16 has an average network capacity of 57.6 kbps, while Link-22 has a maximum network capacity of only 33.44 kbps (using two UHF and two HF networks). However, the actual network capacity depends on the network configuration. For example if the most ECM resistant message packing structure is used the aggregate data rate for Link-16 is only 28.8 kbps, while with the least resistant the data rate is 238.08 kbps.

Network capacity is shared amongst functional groups for both links. This affects the throughput that each unit has access to. With Link-16 a terminal can operate on up to 32 network participation groups (out of the 512 possible groups, although only 22 groups, in the range 0-31, are currently defined) and with Link-22 up to 32 mission area sub-networks are possible.

Over a short time period, the structure of a Link-16 network is essentially fixed to that which it was initialised with (unless timeslot reallocation is used). In comparison, Link-22 can more easily reconfigure in response to situational changes. Automated network management based on network management units make this possible. Although these units make control of Link-22 more centralised than Link-16, the network will still operate in its current structure if the management unit (and its standby unit) becomes disabled.

Although Link-16 and Link-22 use different waveforms, both have similar features. Both are secure, and use error detection and correction (Link-16 uses (31, 15) Reed-Solomon coding and Link-22 uses Reed-Solomon or convolution coding depending on the waveform). In addition Link-16 and Link-22 can both communicate the same messages with the same level of granularity and the same geodetic coordinate system. Link-22 does not however have the relative navigation capability of Link-16 and can only support a maximum of 125 participants rather than 32767. Unlike Link-22, Link-16 has no fast method of transmitting high priority messages.

4.5 Operation of Link-22

4.5.1 Messaging

The Link-22 system transports tactical messages from an originator to one or more destinations using F-series messages. Each message is independent from other messages in the system. A message consists of one or more 72-bit words. Operational data exchange uses messages that relate to participant location and identification, surveillance, electronic warfare, intelligence, weapons control, mission management and status of the participant. Information management messages include track management, update request, correlation, pointer, track identifier, filter, association and correlator change. Weapons coordinating and management messages include command, engagement status, handover, controlling unit, pairing and status. Tactical messages are given a lifetime so that obsolete messages are not relayed. Technical messages are also sent by Link-22 terminals for the purpose of network management.

A message may be a unique, newly defined Link-22 F-series message or it may have embedded in it a J-series Link-16 message (called an FJ-series message). Although F-series messages and J-series messages use the same data elements and geodetic coordinate system, to simplify data forwarding between Link-22 and Link-16, FJ-series messages are preferable.

The data link processor performs the message translations between Link-22 and Link-16. However, appropriate lower level processing and radios are still required to transmit and receive the Link-16 messages. The case is similar for Link-11, however the translation is more complex and can be problematic because of the different levels of granularity for representation. Terminals that include this equipment and translation capability in the Data Link Processor (DLP) are called forwarding units. Typically only selected terminals are forwarding units. STANAG 5616 covers the rules and message translations to forward data between Link-22 and Link-11/Link-16.

Messages are passed between terminals with a number of addressing types. These include point-to-point, radio frequency (RF) neighbourcast, totalcast (all units in the super network), mission area sub-network (MASN), and a dynamic list of units. A MASN is a logical grouping of NILE Units (NUs) to which tactical messages can be addressed. MASNs are similar to Link-16 network participation groups and consist of those NUs that have a related mission.

Different reliability protocols, based on repeat transmissions, are used when a high probability of reception is required.

4.5.2 Network Access

As part of the TDMA system, messages are transmitted in timeslots. Messages are packaged with a header and cyclic redundancy check (CRC) parity bits into network packets. The network packets are sent in timeslots as a number of minislots.

All NUs are assigned timeslots during which they can transmit. This is done automatically during initialization based on calculations done by the network management unit or by each NU (using a common algorithm that is yet to be decided). The allocation of timeslots can be fixed (only changed when the network is re-configured) or dynamic. With dynamic allocation, an automated algorithm (common to each NU) uses donation of timeslots or portions of timeslots (minislots) from NUs with unused capacity, to NUs that require more capacity. This optimizes the network cycle structure to channel capacity needs, channel access delay and other evolving operational conditions.

Within the network cycle structure there are also interrupt slots available for injection of high priority messages. Altogether, there are four levels of priority queues for messages in Link-22. The oldest messages from the highest priority queue are sent first. Lower priority messages are only sent in normal allocated slots, not in interrupt slots.

4.5.3 Network Management

The TDMA architecture used is named nodeless (meaning it is not dependent on any single node, such as a central poller), as it will continue to operate without network managers. However, network management units (one nominated NU) provide automated network management. At the highest level there is a network management unit (NMU) of the super network (collection of all NILE networks in an extended area of responsibility). This unit is responsible for network closedown orders, reconfiguration and re-initialization orders, NU leave and join orders, security orders, allowing late units to join the super network, nominating other NMUs, setting of the relay functions of NUs, radio silence orders and notifying changes in status of units. Under this NMU are other NMUs that manage each of the individual networks. These other NMUs execute the orders of the NMU of the super network. Standby NMUs are nominated that can take over the operation of each NMU when needed.

Late network entry and late traffic entry protocols are used to allow units that were not present at the start of a network to join. These are automated procedures that involve synchronization with the network, negotiation with the NMU and the gaining of current network parameters. The process typically takes between 30 seconds and 4 minutes. An external circuit (such as Link-16) can significantly improve the efficiency of this process.

Within a super network there are two groupings of NUs. At the lowest level is the MASN. Up to 32 MASNs may be established in a super network. The next level of

grouping consists of NILE networks. These are NUs that use the same frequency or frequency-hopping pattern. Up to eight NILE networks can exist in a super network and any NU can operate on up to four networks concurrently. Within the super network, there can be up to 125 NUs.

4.5.4 Terminal Architecture

Figure 1 illustrates the components in a NU terminal.

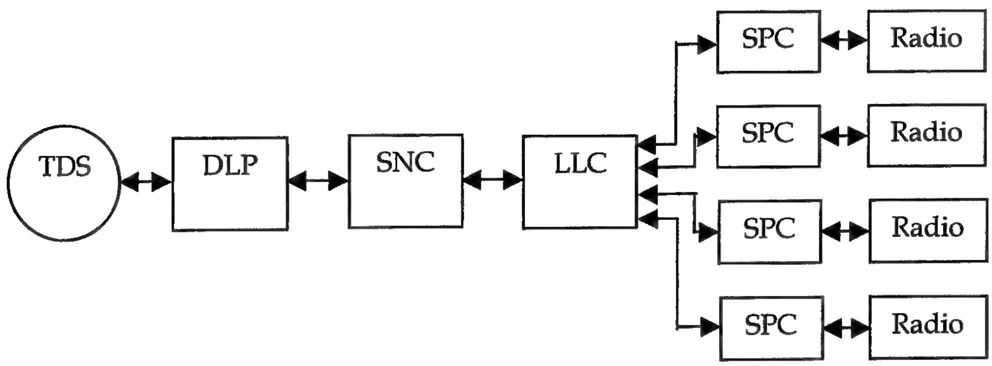


Figure 1: Link-22 system architecture

The tactical data system (TDS) is the source and sink of messages transmitted over Link-22. The data link processor (DLP) interfaces the Link-22 system with a TDS, and with other tactical data links for the purpose of data forwarding. It also interfaces with the system network controller (SNC) and does the presentation layer functions of generating and formatting tactical messages, data translation formatting and syntax selection.

The SNC provides the message delivery service. It is involved in network and unit management and performs dynamic TDMA, relaying and routing, and late network/traffic entry. When the network becomes congested, the SNC performs flow control by asking the DLP which messages it can throw away. It interfaces with the DLP, the link level communications (LLC) security and the time of day source.

Message transmission begins with the DLP sending a Transmission Service Request (TSR) to the SNC. The TSR contains attributes that describe the transmission requirements. The TSR is placed in one of the four priority queues. When all TSRs of higher priority have been serviced, a particular TSR is serviced and the associated message is sent in a free timeslot assigned to the NU. Tactical messages received by the SNC are passed to the DLP.

The LLC is a cryptographic device that provides network security via time of day and user address encryption. This also provides data integrity verification. The LLC

provides an interface between the SNC and up to four Signal Processing Controllers (SPC). This allows the concurrent operation on up to four networks.

4.5.5 Transmission Aspects

The SPC performs modulation and demodulation, as well as error detection and correction. It transmits/receives data at 1493 to 4053 bps for fixed frequency HF operation, at 500 to 2200 bps for frequency hopping HF operation, and at 12667 bps for UHF fixed frequency operation.

The radios provide the physical over the air link between units. Transmission security in HF frequency hopping operation is provided by slow hop radios, and in UHF frequency hopping operation is provided by fast hop SATURN radios. Optional adaptive antenna arrays (as are currently in use by some nations for Link-11) can be used. Using such antennas provides a passive Electromagnetic Protection Measure (EPM) technique that can provide additional suppression of interference and jamming, as well as reduce the effects of antenna pattern irregularities. Optional radio power level control can also be used to lower the probability of intercept. Link 22 does not implement automatic power level control algorithms.

Relaying can be used to link NUs that are separated by more than the RF range. Selected relaying units do this by retransmitting data received for relay in later timeslots (that have been allocated to the unit). The relaying strategy must be decided on before deployment of the link. This involves designating relaying units, allocating sufficient capacity to these units and deciding on whether automatic selection of relaying units should be allowed. Relaying may be within networks or between networks.

Routing is also important in the relaying of messages. For the purpose of relaying, NUs store data on the quality of links between NUs. This is continually and automatically updated. Based on this information, routes via relaying NUs are selected, so that the destination is reached with the least overhead and with a reliable level of probability that the messages will be received.

Note that a significant amount of network planning is required before a Link-22 super network is deployed. Questions such as which units are to be involved, what capacity do units require, what roles will units play, what relay strategy is to be used and what network structure is to be used must be answered.

5. Common Data Link (CDL)

5.1 Introduction

The term Common Data Link (CDL) describes a family of tactical data links. These links are designed for the purpose of supporting reconnaissance and/or surveillance operations. They provide full duplex, wide bandwidth (but asymmetric), point-to-point data communications links between aircraft and ships, or between aircraft and ground bases. This allows the transmission of radar, imagery, video and other sensor information from the aerial platform and the transmission of control data to the aerial platform.

CDL differs from Link-11, Link-16 and Link-22. It is designed to satisfy a specific application, rather than being a more generic data link for processed data as is the case for these other Tadils. Link-11, Link-16 and Link-22 are each capable of sending various types and quantities of information to numerous platforms networked together. In other words these links are flexible enough to suit a range of needs. They are not however capable of the high bandwidths that CDL is capable of. CDL, on the other hand, over a short time interval can only support the transmission of data to one surface platform from one or at most a small number of airborne platforms. The surface platform processes that data and then forwards the appropriate information to other platforms, possibly via one of the other links mentioned.

5.2 Operation of CDL

A CDL system typically consists of the following components:

- Interface to the aircraft sensors and the control system.
- Airborne modem and RF subsystems.
- Surface platform data link processing, modem and RF subsystems.
- Interface to the data users on the surface platform.

Users that require sensor data (on the surface platform) connect to the aircraft via 10 channels within the uplink and up to 25 channels within the downlink. The uplink or command link is the link to the aircraft, and the downlink or return link is the link from the aircraft to the surface platform. Within the uplink there are also channels for executive functions and voice communications. This secure and jam resistant link operates at a standard data rate of 200 kbps. Within the downlink there is also a voice channel. This link can operate at the standard data rates of 10.71 Mbps, 137 Mbps or 274 Mbps and is not secure/jam resistant.

Security is provided by COMSEC encryption and variable depth data interleaving. The use of spread spectrum modulation on the link produces jam resistance. Forward error correction coding is also used.

The system operator on the surface platform typically initiates a data link between a surface platform and an aircraft. Once set-up, data link tracking is automatic and data link functioning is transparent to data users on the surface platform. This allows line-of-sight communications in the Ku band. Beyond line of sight operation is possible with the use of satellite or aircraft relaying platforms.

5.3 Current Status of CDL

Three groups of common data links can be identified. The first group consists of existing CDL systems. These are currently available, used by US and Allied services, and are produced by L-3 Communications. Note that in 1991 the US Department of Defence designated CDL as its standard for use in imagery and signals intelligence. The second group is the Tactical Common Data Link (TCDL). The TCDL is a CDL interoperable data link developed under a US Defence Advanced Research Projects Agency (DARPA) program that began in 1997. The third group is the High Integrity Data Link (HIDL). HIDL is being investigated by the UK for UAVs under sponsorship from the NATO Naval Armaments Group's Projects Group 35. This link is still in the design stage and an implementation date is not available (but is unlikely to be for several years).

The goals of the TCDL program were to develop a family of data links:

- that are low cost and use COTS technology wherever possible.
- that have an open, modular and scaleable architecture so that they can be configured to suit varying applications and can be expanded to satisfy future requirements.
- that are small in size and weight.
- that have an uplink which operates in the 15.15 - 15.35 GHz band and a downlink that operates in the 14.40 - 14.83 GHz band.
- that are able to operate in other frequency bands and with variable data rates.
- that will provide connectivity between TCDL airborne platforms, TCDL surface terminals and currently fielded CDL interoperable systems.

The TCDL program is being conducted in three phases. The initial study, phase one, has been completed. Phase two, in which prototype terminals were designed, developed and delivered, has also been completed. As a result of this two teams have been awarded certification indicating their capability as CDL providers. The first team consists of Harris Corporation and BAE Systems, and the second team consists of L-3 Communications and Rockwell Collins. Prototypes have been successfully demonstrated in the Predator UAV and the Hunter UAV, and currently product development is continuing. Harris and BAe recently won the Light Airborne Multi Purpose System (LAMPS) US Navy contract, which requires both shipboard and helicopter TCDL terminal systems. Phase three (full-scale production) is likely to begin within two years, although some terminals are currently available.

Possible fits of TCDL terminals within the US DoD include manned and unmanned airborne reconnaissance platforms (such as Outrider, Predator, Hunter, Pioneer, Reef Point and others) and P-3 Orions. Vertical takeoff and landing UAVs due for delivery in 2005 will use TCDL terminals, as will MKIII H-60 helicopters and their host surface ships (such DDG 51, FFG 7, DD 963 and CG 47). UK and Denmark are two other possible users of the TCDL.

Although HIDL is also being designed to be CDL interoperable (like TCDL), it is also aimed to complement TCDL. Unlike TCDL, HIDL is designed to be a high integrity link rather than just a wide band link. Both the uplink and downlink are jam resistant (frequency hopping is used), a single control station is able to control multiple data collection platforms and lower frequencies (225 – 400 MHz) are used for greater range. Throughput of 100 kbps will be possible.

5.4 Various CDL Systems

There are a variety of airborne terminals and surface terminals for CDL systems. For the purpose of better understanding CDL, a summary of the parameters of some common terminals is given in Table 4. The last row in the table states the other terminals typically used with a particular terminal. Note that these terminals are for line of sight communications and have a typical range extending up to 560 km.

Table 4a: Features of various CDL terminals

	Common High Bandwidth Data Link (CHBDL)	Limited Capability Common Data Link (LCCDL)	Tactical Interoperable Ground Data Link (TIGDL)	Modular Interoperable Surface Terminal (MIST)
Use	Surface (sea-based) control platform	Air or ground data collection platform	Surface (land-based) control platform, can operate as a FINDS~ terminal for relaying	Surface (land-based) control platform
Frequency Band	Ku	Ku	X (can be extended to Ku)	L – EHF
Weight	Significant	8 kg	Not available	Not available
Data Rates	Uplink – 200 kbps, Downlink – 10.71, 137, 274 Mbps	Uplink – 200 kbps, Downlink - 10.71 Mbps	Uplink – 200 kbps, 2 Mbps, Downlink – 10.71, 137, 274 Mbps	Uplink – 600 bps to 200 kbps, Downlink – 16 kbps to 274 Mbps
Antenna	Two 1m dish antennas	Omni or directional	1.8 m dish	1.8 m dish
Interfaces	BGPHES*, JSIPS^	Optional ATM@	ATM@, CIG/SS#	N/A
Interoperability	CDL data collection terminals	CDL control terminals	CDL data collection terminals	CDL data collection terminals
Operated with	MIDL	MIST or TIGDL	LCCDL or MIDL	LCCDL or MIDL

Table 4b: Features of various CDL terminals

	Modular Interoperable Data Link(MIDL)	TCDL Airborne Terminal	TCDL Ground Terminal
Use	Airborne data collection platform	Airborne data collection platform	Surface (land-based) control platform
Frequency Band	L - EHF	Ku	Ku
Weight	27 kg	7 kg	115 kg
Data Rates	Uplink - 600 bps to 200 kbps, Downlink - 16 kbps to 274 Mbps	Up to 45 Mbps	Up to 45 Mbps
Antenna	Omni or directional	Omni or directional	Omni and directional
Interfaces	1553 bus, navigation system	RS-422 serial, RS-170a, TCS%	RS-422 serial, RS-170a, TCS%
Interoperability	CDL control platforms	CDL control platforms	CDL data collection terminals
Operated with	MIST, CHBDL or TIGDL	TCDL ground terminal, CDL control terminals, can also use for air-to-air operations	TCDL airborne terminal, CDL data collection terminals

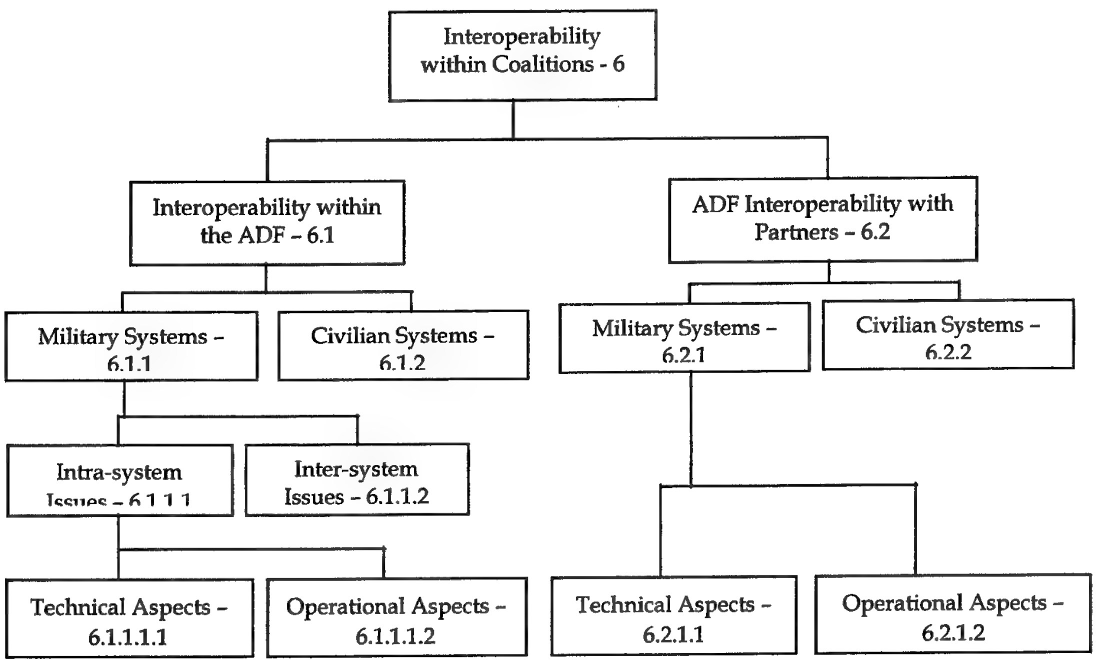
*BGPHES = Battle Group Passive Horizon Extension System
^JSIPS = Joint Services Image Processing System
#CIG/SS = Common Image Ground/Surface Station
%TCS = Tactical Control System
@ATM = Asynchronous Transfer Mode
~FINDS = Flexible Information Dissemination System

With the large number of CDL terminals, interoperability becomes an important issue. There are two levels of interoperability. At the data link level, interoperability between any control platform (typically a surface platform) and any data collection platform (typically an airborne platform) is ensured by having compatible data rates, modulation techniques and transmission frequencies. The interoperability row in the table is related to this.

At a higher level, interoperability depends on compatibility between the systems that the control terminal is interfaced to and the systems the data collection terminal is interfaced to. This is necessary for the control terminal to be able to control the airborne terminal and for it to be able to extract readable sensor data. For example, a CDL interoperable control platform and a CDL interoperable data collection platform that both have interfaces to JSIPS (Joint Services Image Processing System – a source and sink for transmitted data) will be able to communicate with each other. This level of interoperability depends on the terminals used and some of the known interfaces for terminals are shown in Table 4. This is not a comprehensive list, as not all interfaces are known.

Recent activities related to interoperability include the US Navy-CHBDL Demo in 2000 and the work of the Sensor Interface Working Group (SIWG). The Navy-CHBDL Demo showed CHBDL interoperability with legacy CDL equipment and video recovery through CHBDL was possible. Since 1999 the SIWG has been helping to shape the interfaces to the CDL products to ensure interoperability between all sensor solutions and CDL providers.

6. Tactical Data Link Interoperability from an Australian Perspective



The architectural drivers for using Tactical Data Links within a coalition environment are as follows:

- Common communications/message standard
- Common message format
- Common understanding of use and interpretation of messages
- Sharing of a common tactical picture
- Secure communications
- Low data latency
- Integrated voice for C2 – avoid bespoke systems
- Low bit error rate
- Scalable & adaptable
- Open architecture – expandable

Although not all of these aspects are fully met by existing TDL standards all are met to a certain degree. The real power in these networks is the interoperability as standards for these links are agreed at international fora thus allowing greater scope of national participants in international coalitions.

This chapter covers general information on achieving interoperability, plus specific issues faced by Australia where information is available.

The US SPAWAR organisation is now espousing the opinion that design of systems should not be about building platforms but to first build a network and then platforms to fit the network. However building coalition networks cannot be made to fit this paradigm. Coalition networks are built in an *ad hoc* manner from capability modules. Adherence to international standards, technical and operational, are the only way interoperability can be assured.

Coalition networks need to be designed from an inventory of extant TADILS equipped platforms. Efficiency demands plug and play principles, which require high levels of flexibility and effectiveness in interoperability across the spectrum from technical to operational. Operational interoperability is maintained through coalition exercises.

When operating a coalition network the following Joint network management assets are required:

- Staffing for net planning
- Staffing responsible for net management
- Required connectivity - important as it affects the accurate distribution of the COP, also what information will be shared and what will not be.
- Architecture and assignment of gateway roles - where should the gateways be, who will operate them.
- Crypto key distribution

For Australian interoperability with NATO countries, the NATO Interoperability Framework is important. It consists of:

- A policy aspect (NATO Policy for C3 Interoperability), an execution aspect (NATO Command, Control and Communications (C3) Interoperability Management Plan and Five Year Rolling Interoperability Programme) and products (NATO C3 Interoperability Environment).
- The Policy involves the mandatory use of selected standards and products for all new or substantially modified NATO common or partially common funded C3 systems. It includes determining interoperability requirements, interoperability testing and determining interoperability deficiencies.
- The NATO C3 Interoperability Environment (NIE) encompasses the standards, products, and agreements adopted by the Alliance to ensure C3 interoperability. It serves as a basis for the development and evolution of C3 systems. The NATO C2 Technical Architecture is a key part of the NIE.

- NATO Technical Architecture ADatP-34.

Practical aspects of Link-16 deployment indicate the need for a deployed communications node to manage large coalition networks. Link-16 was design to have a reduced management overhead, however the complexity of the networks indicates a need for more management, with the implication for extra staffing, to ensure interoperability remains effective. The implications are that an extensive deliberate planning phase must be followed up with solid network management during deployment.

6.1 TDL Interoperability within the Australian Defence Force (ADF)

There is a requirement for a consistent Common Operating Picture distributed to all necessary personnel within the ADF. There needs to be an awareness of the degree to which this can be done and possible inaccuracies within it. Also, appropriate levels of detail need to be presented to the appropriate personnel in different roles. In order to achieve this a detailed CONcept of OPerationS (CONOPS) needs to be developed, however to achieve this an understanding of the network's capability must be developed. Controlled exercises play an important role in developing CONOPS.

Network Design depends on:

- Detailed knowledge of the number of platforms and their capabilities
- Knowledge of what information is to be shared and what advantage it will bring, ie a way to value the information
- An understanding of the type of geographical region the network will operate under – range and propagation limitations
- How the various TDL standards will interoperate through gateways and data forwarding
- Location and roles of platforms suitable for relay
- Location and roles of platforms in the coalition force that are not TDLs enabled.
- Limitations on data accuracy and latency when forwarded over wide area networks

Network management involves:

- Use of resources so that the necessary connectivity is available taking into consideration lower level interoperability issues
- Assigning roles and information flows commensurate with platform capabilities
- Assigning roles to platforms (such as gateways/relaying)
- Staffing
- Architecture for use for multi TDLs operation based on information exchange requirements. There are operational roles where one TDL standard will be more suitable than another. Informed selection will optimise overall system performance.
- Crypto key distribution

Australian Defence Force Tactical data links Authority (ADFTA):

- Coordination of interoperability testing, assessment and improvement
- System management through use of the ThroUgh Life Interoperability Planning (TULIP) process
- Involvement in data interoperability, functional testing of equipment, providing operational network designs and providing tactical data link training

TULIP is a structured through project life cycle process. It provides a method to plan for interoperability from the start and continuously assess interoperability. National and platform specifications are used to enhance STANAGs/MIL-STDs for all platforms implementing TDLs.

TULIP includes:

- A single TDLs authority
- TDL implementation and testing policies
- Detailed TDLs standards
- Detailed platform specification documents
- Integration development testing and feedback processes
- Interoperability review, analysis, testing and feedback processes
- Supporting tools and configuration management procedures

Of interest to Australia may be the method with which the US DoD is approaching interoperability:

- A framework was developed called the Defence Information Infrastructure Common Operating Environment (DII COE) together with the Joint Technical Architecture (JTA) and the Technical Reference Model (TRM).
- DII COE provides an approach for building an interoperable system and a framework for system development and integration. This includes an automated process for software integration, an electronic process for submitting/retrieving software components to/from the COE repository and a set of requirements for achieving COE compliance. The COE is a solution to the interoperability problems of having many stovepipe solutions designed for particular functions.
- The Levels of Information System Interoperability (LISI) model provides a structured approach to assist in interoperability and integration maturity models, processes and solutions. As the levels of interoperability are clearly articulated, it guides discussion and collaboration on interoperability capabilities options for implementation and assessment processes.
- The TRM provides planners and designers with a tool to identify information technology (IT) services and interfaces required to achieve interoperability. The JTA provides a minimal set of standards jointly adopted for services and interfaces to achieve interoperability.

Similarly, in the UK, the Defence Technical Architecture is used by procurement staff and industry. Key features are:

- Based on commercial technology/standards wherever possible.
- Build for now with controlled migration path for future.
- Minimum constraint necessary for interoperability (Defence Interoperability Environment)
- Describes additional standards and processes to facilitate people and application portability (UK Defence Common Operating Environment)
- Policies and processes necessary to ensure the development and adoption of the Defence Technical Architecture.
- Is dynamic – it reflects changes in technology whilst maintaining compatibility with the past.
- The UK will leverage off the NATO technical architecture document ADatP-34.

Software packages that help with determining interoperability include the Joint Operations Tactical Interoperability Database (JOTID) and DAKIS.

Joint training of staff in network design, monitoring and utilisation is seen as an essential process to ensure interoperability across the Forces.

6.1.1 Military Systems

Issues to consider:

- Migration/evolution of systems, management of upgrades, version control, configuration management.
- Difference between TDL capability between various force elements making up the task force.
- Differences in requirement to update the tactical COP for various roles of platforms.
- How to integrate new advanced TDLs concepts or terminals into existing communications architecture.
- How integration with new equipment (such as new weapons) will occur.
- Data forwarding of Common Operating Picture (COP) beyond Tadils networks.

6.1.1.1 Intra-system Issues

For the interoperability of all the terminals within a particular data link system, both technical and procedural compatibility must be solved.

The US has had problems with the message standard authority not being duly recognised. This has led to the same messages, although following standards, not being processed equivalently by different platforms.

Training in the use of tactical data links must be maintained and to maintain Joint capability training should cover joint operational aspects.

6.1.1.1.1 Technical Aspects

For each data link system, there must be compatible waveforms, protocols/standards, message format, and message data elements. This necessitates compatible terminal hardware and software. The host combat system that the communications terminal is integrated with, may also affect interoperability with other platforms. A summary of these issues for each link is as follows:

LINK-16:

- STANAG 5516 – defines the Link-16 message standard. Additional National-level documentation is needed to support this as 5516 has insufficient detail for a complete standardised implementation (according to US and UK experience).
- STANAG 4175 – defines terminal requirements
- Small incompatibilities between terminal builds – IJMS, JTIDS class 2, MIDS LVT 1, MIDS LVT 2, MIDS LVT 3
- Differences between host equipment – Model 4 JTIDS has a non J-series based message database, while Model 5 JTIDS does have a database based on J-series messages.
- L-16 Missile & Tactical Terminal (LMT2) - 100 cubic inch terminal that is under development with optimised relative navigation capability. Interoperability will be constrained by the fact that it will not contain voice or TACAN capability and will have reduced power output. It will simplify compilation of the single integrated air picture (SIAP) as equipped missiles will be able to be included in the picture.

LINK-11:

- STANAG 5511 – defines Link-11. Additional national-level documentation is necessary to standardise national implementations due to the imprecise nature of the standard and the options available. Two different waveforms are now available – Conventional Link Eleven Waveform (CLEW) and Single-tone Link Eleven Waveform (SLEW).

LINK-22:

- STANAG 5522 and Link-22 System Specification – define implementation of Link-22.

Regardless of the TADILs technologies, compliance across versions must be considered. A limited range of platform software/hardware fits has been found helpful in the UK.

When fusing data sourced from a TADILs network, incompatibility between sensors needs to be investigated at the technical level. Failure to do so may result in an incorrect picture.

6.1.1.1.2 Operational Aspects

Issues that must be considered include:

- Data link planning and management, including relaying, procedures on how the link is to be used. The procedures for Link-16 are covered in the NATO Standard.
- Operating Procedures for Link-16 (AdatP-16) and STANAG 5516 and the equivalents for Link-11 (AdatP-11 and STANAG 5511).
- Quality of information/track reporting – its update rate, resolution, reliability, accuracy. This is affected by operator errors, sensor accuracy, correlation/fusion of data from different sources (e.g. is a common algorithm used?).
- Message usage – interpretation, presentation, filtering (partially OPSPEC 516.2)
- How to handle network faults/outages
- Training
- Interoperability testing – an effective procedure is needed as often limited resources prevent the "test everything" approach.
- Control of assets through Link-16 needs to be designed in and not added in afterwards
- Platform implementation problems have arisen in the US and the UK despite best efforts – *all* fits must be coordinated at the national level.
- The key to a high level of interoperability is to have an adequate CONOPS.

6.1.1.2 Inter-system Issues

This section considers message transfer between Link-16, Link-11, Link-22 and satcom (e.g. S-TADIL-J).

To be able to pass messages between these different data link systems, gateways must be used to perform communications protocol translation and message translation. Issues to be considered in message translation are outlined in the Table 5 below.

Multi-TDLs processors may be used on platforms to control multiple data link terminals and the translation between data links.

Data forwarding between Link-16 and Link-11, Link-16 and Link-22, and Link-11 and Link-22 is covered in STANAG 5616 and in the US equivalent document MIL-STD-6016B.

Table 5: Interoperability between various data link systems

	Link-11	Link-22	Satellite Link-16
Link-16	Message translations are carried out in the C2P/DLPS of the Link-16 system.[1,2] Typically only C^2 systems have data forwarding capability, but some other platforms are capable of concurrent operations.	Message translation capability will be available in future multi-TADIL processors (replacements for C2P).[1]	Some systems include the message translation capability in the C2P/DLPS for data forwarding or concurrent operations.[1,3]
Link-11		Message translation capability will be available in future multi-TADIL processors (replacements for C2P).[1,2]	Some systems include the message translation capability in the C2P/DLPS for data forwarding or concurrent operations.[1,3]
Link-22			Future multi-TADIL processors will enable interoperability.[1]

Notes
1. Communications equipment, to produce compatible waveforms, is also necessary.
2. Message translation is complex and can be problematic because of the different levels of granularity for representation.
3. Any particular data link system is only interoperable with one of the satellite Link-16 versions. These incompatible links include the Royal Navy's Satellite Tactical Data Link (STDL), the US Navy's S-TADIL-J and the US Air Force's JTIDS Range Extension (JRE). S-TADIL-J is being developed by the C2P community as a range extension mechanism.
4. The US is re-hosting the C2P onto a more capable processor while making it an open software architecture.
5. The Royal Navy are developing a C2P-like system called the Data Link Processing System (DLPS) for their surface fleet to deal with Link-11, Link-16, Link-22 and the UK's STDL.

Other issues that must also be considered are:

a. Allocation of limited spectrum to all communications systems and assessment of the impact on civilian systems.
b. Use of satellite bandwidth.
c. Compatible terminal addressing
d. Different ID processing or display limitations for tracks may cause problems.

Location and identification of own assets may not always be achieved through TADILs. To achieve a coherent common operating picture with low probability of fratricide it is necessary to plan how systems other than TADILs will interoperate. A particular problem is the sending and receipt compliance of orders across TADILs/non-TADILs systems.

The USAF are investigating a system with an interface for JTIDS, Situation Awareness Data Link (SADL) and Theatre Information Broadcast System (TIBS) with Common Data Link (CDL) and Recce Intel Data Exchange datalink. Considerable interest has been shown in developing systems that fuse information from a range of datalinks into a common product.

Products are now available that will provide data forwarding in a more general sense. These systems are implemented as an object-based data base and the input from TADILs and other sensor links is used to update the objects. The state of the objects can then be shared around the battlespace on a variety of communications bearers using various protocol, including internet protocols.

One of the aforementioned products for fusing TADILs and non-TADILs information is ANZUS's Rosetta engine. One product based on this data-base system is Joint Moving Map Tactical Information Display Systems (JMMTIDS) which can receive raw JTIDS signals and undertake all processing and allows any terminal on a ship with TCP-IP (Internet Protocol) access to view near real-time TADILs picture super-imposed on a map. The Rosetta product will also deal with a Variable Message Format (VMF) source. VMF is a messaging standard, a member of the "J-Series family", compatible with Link-16.

6.1.2 Civilian Systems

The main method of interaction between Military TADILs systems and civilian communications system is through the sharing of the electromagnetic spectrum band. Link-16 is a secondary user of the Radio Navigation Band. The new GPS L5 and the European Galileo safety of life services have had spectrum allocated as primary users that overlaps the top 17 frequencies of the JTIDS waveform.

- ADF communications systems must not interfere with Australian civilian navigational communications systems (Distance Measuring Equipment (DME) and future L5) - as a secondary user, JTIDS/MIDS shall not cause harmful interference.
- ADF communications systems must satisfy frequency spectrum clearance agreements made with the Australian Spectrum Authority (ASA) (spectrum usage, power emission levels, pulse densities)
- Nations have to separately agree to get clearances to get near international agreement for frequency clearance.

Specific JTIDS restrictions that need to be adhered to for planning and operation include:

- Timeslot duty factor limits should be adhered to - inhibit transmitters when authorised limits are exceeded.
- Minimum separation distances between any airborne JTIDS/MIDS terminal and
  - ground/surface navigation TACAN/DME - 0.5 nm
  - secondary surveillance radar - 900 ft
  - airborne Auto Transponder Communications (ATC) - 1000 ft
  - another JTIDS/MIDS terminal when operating in contention mode 100 nm (violates timeslot duty factor restrictions)

The sharing of the Radio Navigation spectrum places quite severe restrictions on what can be undertaken in trials and exercises.

6.2 ADF Interoperability with Partners

The interoperability frameworks being adopted are based on NATO STANAG documents. We need to maintain a watching brief of our allies' implementation and the operational approach decided upon as a result of the framework chosen by the partner. As mentioned earlier in the report, the standards are constantly under review and being updated.

Some examples of problems that have arisen include:

- incorrect network time update
- track instability
- incorrect messages being sent
- database corruption
- incorrect data forwarding
- incorrect crypto option selection

6.2.1 Military Systems

Evolution of systems and standards (particularly of major allies of Australia) are important as it affects ADF planning and future interoperability with partners, for example, the migration of US DoD to Link-16 family TDLs (as defined in their Joint Tactical Data Link Management Plan).

Gateway relays for data translation and transmission between differing networks may not meet exact requirements for network centric warfare but may provide sensor-to-shooter capabilities for some applications. For very high performance networks that require exchange of raw sensor data, TADILs and these gateway mechanisms are not suitable.

Internationally, the philosophy of building the network first is gaining ground. The Eurofighter has been designed specifically to be an element in a network. The USAF and USN are also adopting this philosophy.

The USN has stated that it is committed to maintain Link-11 for approximately the next 7 years.

6.2.1.1 *Technical Aspects*

In addition to using the same international standards for data links, the ADF must ensure that its specific communications terminals and message formats/data elements are compatible with partners. This is because the international standards tend not to specify enough detail for implementation.

6.2.1.2 *Operational Aspects*

Any network design will need dynamic adjustment since not all assets will operate at full specification, it is not known how the enemy will respond or how the plan will cope with the removal of an element from the network. These aspects become more complex when operating a multi-national coalition network.

During Kosovo the UK supported the coalition Link-16 network with a Transportable Interoperability Monitor (TIM) that allowed real-time data analysis and monitoring. A product named Multi-link Interoperability Data Analysis System (MIDAS) provided real-time network management. Operational issues include:

- Compatibility between nations' procedures in the use of data link systems.
- Information contained in messages needs to be interpreted in the same way by all coalition forces.
- Displays and integrated systems capability mismatch
- AEW&C control of mixed forces

6.2.2 Civilian Systems

Intersystem issues of importance are:

- ADF communications systems must not interfere with civilian communications systems within the region of operation.
- ADF communications systems must satisfy any spectrum regulation within the region of operation.
- As the COP is classified there would not appear to be a need to share the data with Non-Government Organisations (NGOs) or the civilian population.

7. Concluding Remarks

In this report we have looked at a range of technologies and issues likely to affect the near and medium term future of data links and tactical communications. There is no doubt that there is an increasing requirement to be able to share the situational picture of the tactical environment amongst a wide variety of platforms, in near real time.

The developments in TDLs and the processes being applied to improve system interoperability are aimed at enabling this information sharing to take place reliably and in a timely fashion amongst platforms that require access to it. By creating an up-to-date and accurate COP, fratricide can be reduced and an improved ability to dominate the battlespace can be attained.

The ADF has the advantage of being able to observe the development and events that have taken place so far in the international arena in the move towards this goal. As Australia looks to increase its capability in this area it is able to learn from the successes and mistakes that have already been made by others.

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19. ABSTRACT

With the increasing importance of sharing computer-based information between tactical platforms, the Australian Defence Force (ADF) is aware of the need to enhance its ability to distribute such information, to those who need it, in a timely fashion.

There are many systems available or being developed that can contribute to meeting this requirement. This report describes the capabilities provided by a selection of technologies, considered to be of potential relevance to the ADF. This includes enhancements to Link-16, the Improved Data Modem (IDM), Link-22 and the Common Data Link (CDL).

A discussion of the interoperability issues that need to be considered when implementing any such systems in the ADF, is also included.

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